Report 2319

ROTATING BIOLOGICAL CONTACTORS FOR MUNITIONS WASTEWATER TREATMENT

by

P. Gail Chesler

and

Gerald R. Eskelund

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report documents investigation of the applicability of aerobic rotating biological contactor (RBC) technology for secondary treatment of the wastestream of a facility manufacturing the explosives RDX and HMX. The synthesized wastestream contained high levels of formaldehyde and formic acid as well as the explosives RDX, HMX, and TNT. Several other organic contaminants were also present in lesser concentrations. It was found that the RBC was capable of removing 82% of the Chemical Oxygen Demand (COD) from the wastestream at loading rates of 2.3 lb of COD per 1000 ft^2 of disc surface area per day.

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SUMMARY

This study investigated the treatability of a synthesized waste stream simulating a munitions plant wastewater effluent using rotating biological contactor (RBC) technology. Synthesis of the waste stream was based on anticipated compositions and flows from a munitions plant, designated as RDX/HMX Site X Facility. The study was conducted using a bench-scale aerobic biodisc unit.

Seventeen constituents were used in the formulation of the wastewaters, including formaldehyde, formic and acetic acids, solvents, RDX, HMX, TNT, and other contaminants in lesser amounts. Three influent compositions were used in the testing. Two of them contained the same contaminants, but one was made more dilute by inclusion of condensate from a heat exhanger. The third composition represented a plant effluent which would result if pretreatment of the ammonia-still-bottoms was bypassed.

Based on the results of the investigation, the following conclusions can be drawn:

a. At an average loading of 2.3 lb COD/1000 ft^2 day, removal of 82% of COD was attained in treatment of the more dilute wastestream in the testing performed in October through December.

b. In the testing which was performed in June through August, a higher loading of 3.6 lb COD/1000 ft^2 day gave the same COD removal.

c. In the treatment of the more concentrated wastestream, removals of 62% of COD were attained at a loading of 2.3 lb COD/1000 ft^2 day.

d. pH values near 3 of the influent hinder biological treatment. The influent must be neutralized prior to treatment.

e. Phosphorus and nitrogen supplements were necessary to allow growth of microorganisms. Calculations indicate that requirements for nitrogen and phosphorus at the plant level would be quite high.

f. Formaldehyde and formic acid in the high concentrations used were not toxic to the microorganisms.

g. Several different microorganisms populated the aerobic biodisc unit. Many were typical of sewage treatment plant microorganisms.

h. The microorganisms which populated the system were extremely hardy, indicating that the possibility of a total kill-off was remote.

i. Filtering was a problem with this culture on both sand and carbon filter columns due to the spore-forming nature of the microorganisms.

j. High levels of COD reduction will occur in the equalization pond used in the proposed X-Facility treatment system if pH neutralization is provided.

PREFACE

The investigation covered by this report was requested by the US Army Munitions Production Base Modernization Agency and funded by the Corps of Engineers, Huntsville, under Procurement Work Directive APO3SQ5 from Commander, ARRADCOM to Commander, MERADCOM. Work was accomplished under the direction of Chief, Environmental Technology Branch, Petroleum and Environmental Technology Division, Energy and Water Resources Laboratory, MERADCOM and the Task Director, Dr. John Thomas, X-Facility Wastewater Treatability Study, Chemical Systems Laboratory, US Army ARRADCOM.

The investigation was conducted by the following personnel of the Petroleum and Environmental Technology Division:

Gerald R. Eskelund, Branch Chief.
P. Gail Chesler, Physical Scientist.
Elizabeth Radoski, Chemist.
Janet O. Hall, Chemist.
Donald Miller, Technician.

Microbiological work conducted at Natick Laboratory by Neil G. McCormick and Bonnie J. Wiley, as well as assistance received from the Atlantic Research Corporation team, is acknowledged.

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Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric tons	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	L
pt	pints	0.47	liters	L
qt	quarts	0.95	liters	L
gal	gallons	3.8	liters	L
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in = 2.54 cm (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10 000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric tons (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
L	liters	2.1	pints	pt
L	liters	1.06	quarts	qt
L	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

ROTATING BIOLOGICAL CONTACTORS FOR MUNITIONS WASTEWATER TREATMENT

I. INTRODUCTION

In 1977, the Army began the concept design for a new facility which will manufacture the explosives RDX and HMX. The facility, designated as RDX/HMX Site X, will incorporate not only the explosives production, but all of the other processes necessary to manufacture and blend the explosives. These ancillary processes will include nitric acid production, acetic acid dehydration, acetic ahydride production, explosives formulation and blending, and wastewater treatment. It is anticipated that the X Facility will discharge between 1.0 and 1.5 million gallons per day with two production lines initially in full operation. Two additional lines may eventually be built at this facility.

Three sites have been chosen as potential locations for the facility, and negotiations with regional offices of the Environmental Protection Agency have begun to determine the National Pollution Discharge Elimination System (NPDES) permit requirements for each site. The specified effluent standards will determine the level of wastewater treatment required.

Studies conducted at Holston Army Ammunition Plant (HAAP) and Radford Army Ammunition Plant (RAAP) indicated that treatment of munitions wastewaters by a biological system was feasible. At HAAP, an activated sludge plant was used on wastes somewhat similar to those expected at the X Facility; while at RAAP, an RBC was tested on wastes markedly different from those expected. The current investigation was to determine whether RBC's could be used on X-Facility effluent.

In the preparation of a Project Development Brochure (PDB-1) by the US Army Engineers, a concept for a three-level treatment process employing RBC's was developed. This concept is illustrated in Figure 1.

Primary treatment was to consist of oil/solids separation, equalization, and pH adjustment. In the secondary treatment, RBC's were to be used to reduce the Biochemical Oxygen Demand (BOD_5) of the effluent to acceptable levels. After the biological treatment, the sludge was to be removed and prepared for disposal. The tertiary treatment consisted of dual-media filtration and carbon adsorption.

Since the design generated was based on calculations rather than experimental data, bench- and pilot-scale testing were appropriate. Bench-scale testing took

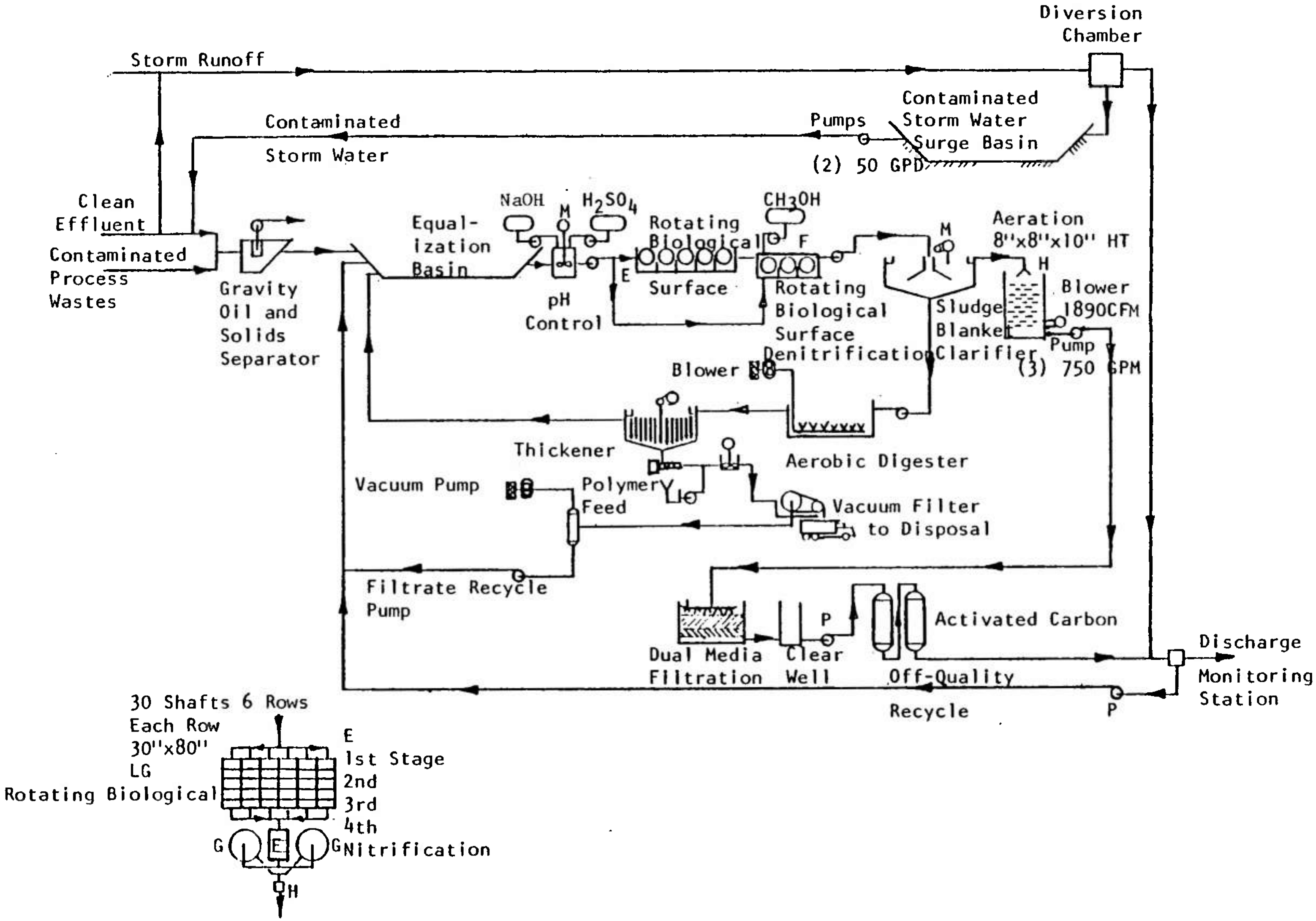

Figure 1. RDX/HMX Waste treatment process flow diagram (U.S. Army Engineers, Huntsville, 1977).

place at MERADCOM and pilot-scale testing took place at Atlantic Research Corporation (ARC) beginning in April 1979.

II. PROGRAM OBJECTIVES

Investigation was designed to provide answers to the following questions:

Can RBC technology be used to remove organic material from wastewater synthesized to simulate X-Facility effluent?

Is 95% reduction in Biochemical Oxygen Demand possible using the RBC process?

What initial hydraulic loading should be recommended for the pilot-scale unit? Are there conditions of which they should be forewarned?

Is scale-up from bench-scale to pilot-scale possible; i.e., will the same loading in pounds of BOD_5 per 1000 ft^2 of disc area result in the same removal efficiency?

Can wastewater from the ammonia still be used as a nitrogen source for the microorganisms? This would eliminate the necessity for separate pretreatment of this wastewater.

III. EXPERIMENTAL PROCEDURES

1. **Test Waters.** Three compositions were specified for the test waters to be used in this study. They are designated A stream, B stream, and ammonia-still-bypass water. The predicted chemical compositions of the A and B streams are shown in Table 1. These wastewater compositions were predicted by ARRADCOM. Table 2 gives the compositions of wastewater used in this investigation.

Adjustment of pH for A and B streams was made using ammonium hydroxide on a batch basis in amounts sufficient to raise the pH to approximately 7.4. Approximately 250 ml of 15N NH_4OH was added for neutralization in the 1100-litre mix initially prepared which represented an addition of 54 grams of nitrogen. The 1N NH_4OH which was used in the continuous adjustment system also added nitrogen. Less than 3 litres of 1N NH_4OH was used with each 1100-litre batch; the exact amount was not recorded. Fine tuning for leanest nitrogen feed was not done at the bench-scale level, although the pilot-scale unit did fine tune this addition.

Table 1. Predicted Composition of Influent to Wastewater Treatment Plant X Facility

	Stream A		Stream B	
	Total Flow (gallons/day)			
	1,539,800		993,600	
Contaminants	lb/day	mg/l	lb/day	mg/l
NO_3-NO_2	230	18	225	27
Ammonia	19-46	2-4	19-46	2-6
RDX	60-147	5-11	60-147	7-18
HMX	20	2	20	2
TNT	64-155	5-12	64-155	8-19
Acetic Acid	420-1052	33-82	420-1052	51-127
Hexamine	464-576	36-45	464-576	56-70
Cyclohexanone	518-648	40-51	518-648	63-78
Propyl Alcohol	653-816	51-64	653-816	80-99
Methyl Acetate	250-312	20-24	250-312	30-38
Propyl Acetate	77-96	6-7	77-96	9-12
Formic Acid	2246-2808	175-219	2246-2808	272-339
Nitromethane	250-312	20-24	250-312	30-38
Formaldehyde	6912-8640	539-674	6912-8640	836-1045
Phosphate	66	5	66	7
Sulfate	1102	86	829	100
Acetic Anhydride	400	37	400	48
Amine	60	5	60	7
Organic Nitrogen	69	5	69	8
Toluene	38-48	3-4	38-48	5-6
Stearic Acid	12-24	1-2	12-24	1-3
Acetone	566-696	43-54	566-696	67-84

Stream A: Total wastewater includes heat-exchanger condensate.

Stream B: Total wastewater without heat-exchanger condensate.

Table 2. Chemical Composition and Characteristics of the Test Waters

Chemical	Stream A (mg/l) Includes heat-exchanger condensate	Stream B (mg/l) Excludes heat-exchanger condensate	Ammonia-Still-Bypass Water (mg/l)
Formaldehyde	674	1045	1045
Formic Acid	219	339	339
Sulfate	86	100	100
Acetic Acid	85	184	184
1-Propanol	64	99	99
Acetone	54	84	84
Cyclohexanone	51	78	78
Hexamine	44	70	355
Methyl Acetate	24	38	38
Nitromethane	24	38	38
n-Propyl Acetate	7	12	12
Phosphate	5	7	7
Toluene	4	6	6
Amines	5	7	344
Stearic Acid	2	3	3
TNT	12	19	19
RDX and HMX	13	20	20
COD	1650	2300	2300
BOD	1390	1660	1660
pH	3	3	3
Sodium Bicarbonate	0	0	114
Ammonia	0	0	1009

During the initial startup of the system, it became apparent that nitrogen and phosphorus concentrations were inadequate for support of bacterial growth. As a result, additions of ammonium hydroxide, as mentioned, and sodium phosphate were made to the test waters.

The amount of phosphorus to be added was calculated as a molar ratio of carbon to phosphorus of 106 to 1. Microorganisms are thought to use carbon, nitrogen, and phosphorus for synthesis in a molar ratio of 106 to 16 to 1.

One modification was made to the feed itself. At startup, the explosives were not used in the feed mixture. However, once RDX, HMX, and TNT were included, it was important that they be completely dissolved to be sure they were included in the feed stream to the biodisc. In order to facilitate complete mixing, it was necessary to enhance the solubility of the RDX and HMX by addition to the wastestream of more cyclohexanone than the formula specified. Sufficient acetone was present in the formula to insure the solubility of the TNT. For reasons to be discussed later, RDX, HMX, TNT, and the supplemental cyclohexanone, were deleted from the feed stream for the last two phases of the testing.

2. **Equipment.** Two physical setups were used in the bench-scale testing. Figure 2 illustrates the complete treatment scheme as employed to simulate the plant. Because of operational difficulties, several pieces of equipment were removed after the first month of testing, leaving the system as shown in Figure 3 for use in the remaining testing.

In the initial phase of the testing, a covered 1100-litre tank was used to hold the synthesized wastestream. The waste was pumped into a smaller 120-litre feed tank. Flow from this tank into the aerobic biodisc was controlled by a Masterflex pump. Uniform mixing in both tanks was accomplished by use of submerged pumps.

The aerobic unit is shown in Figure 4. This four-chamber unit was constructed in-house of 0.6-cm (¼-in.) Plexiglas. Each chamber contained six Plexiglas discs of 26.04-cm (10¼-in.) diameter mounted on a shaft of 1.3-cm (½-in.) diameter. One hundred ninety-five holes of 0.6 cm (¼ in.) diameter were bored into each disc to aid in microorganism attachment. The total disc area was 2.5 m^2 (27.5 ft^2). The liquid capacity of the aerobic biodisc unit was 9 litres. The discs rotated at 17.5 rpm. This speed is equivalent to an edge velocity of 0.24 m/s (0.78 ft/s). Effluent from the aerobic biodisc flowed into the anaerobic biodisc unit which was covered and airtight. The capacity of the anaerobic unit was 60 litres.

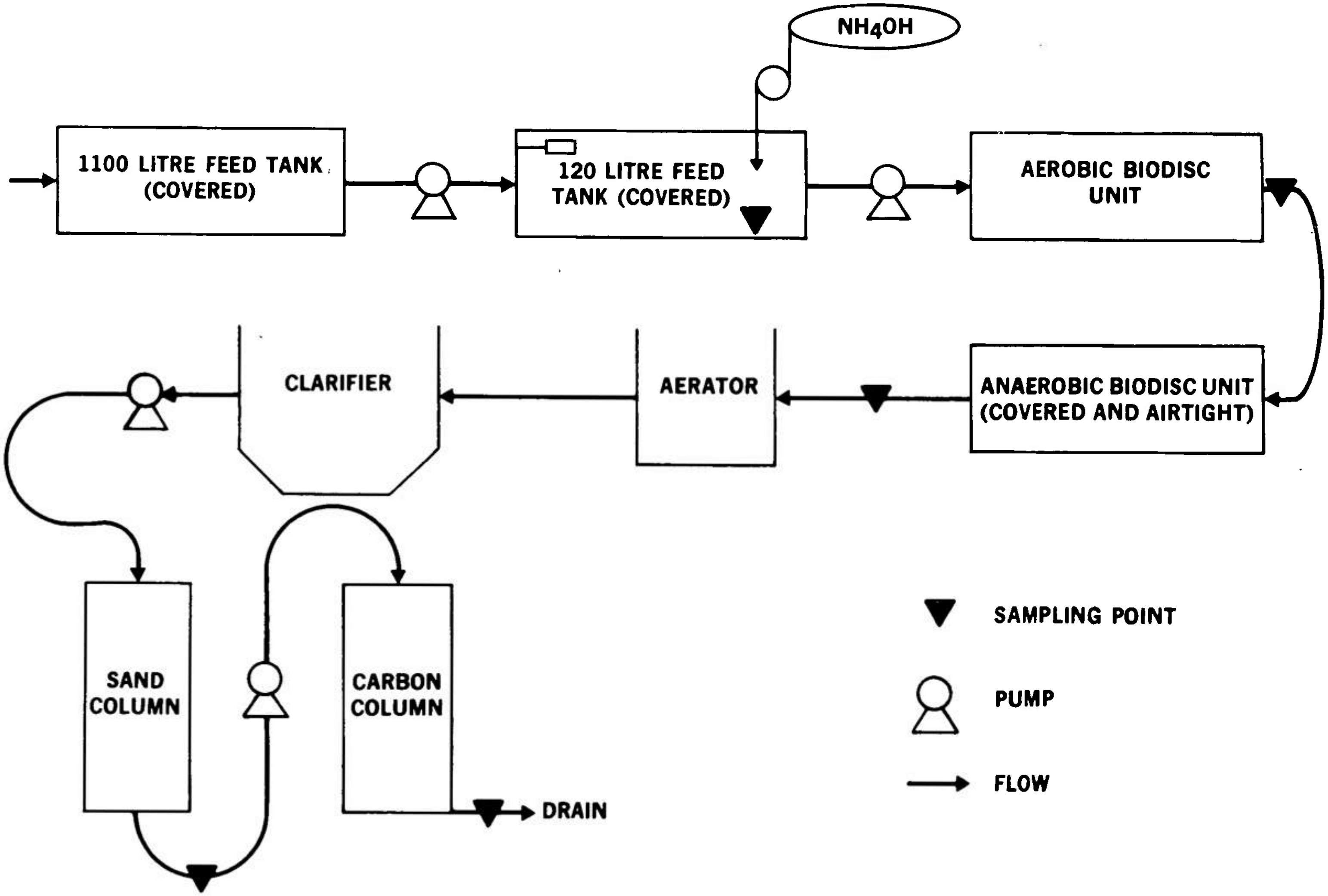

Figure 2. Original bench-scale test setup.

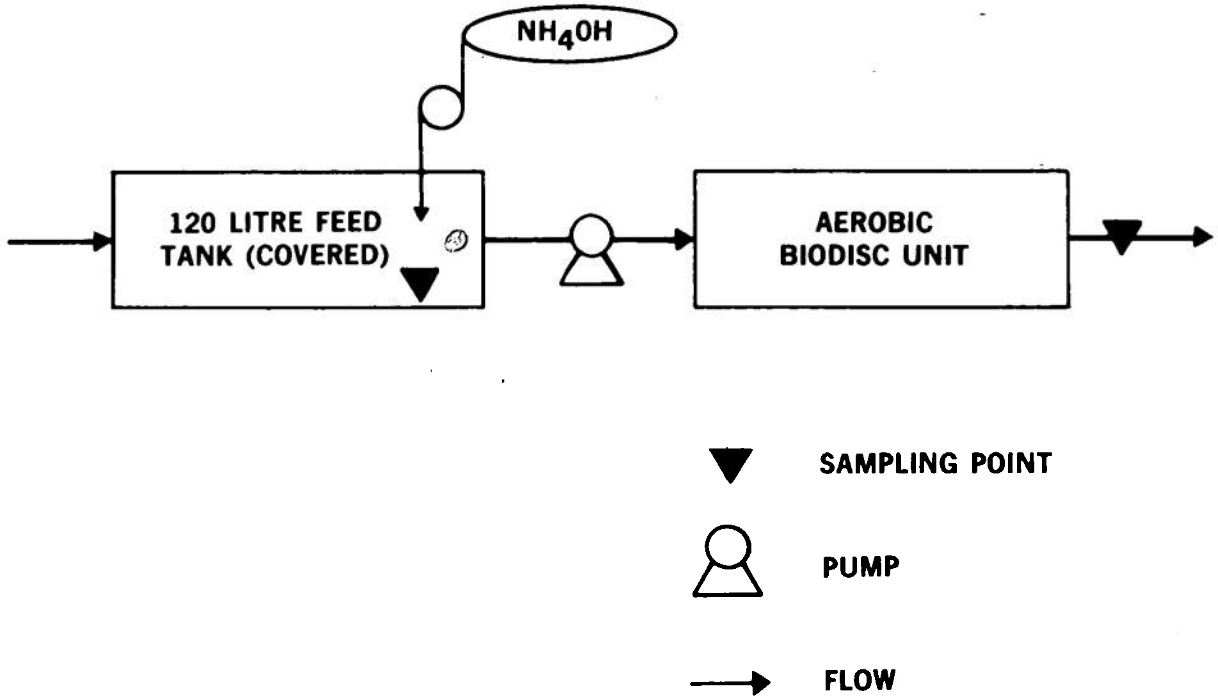

Figure 3. Bench-scale test setup as revised.

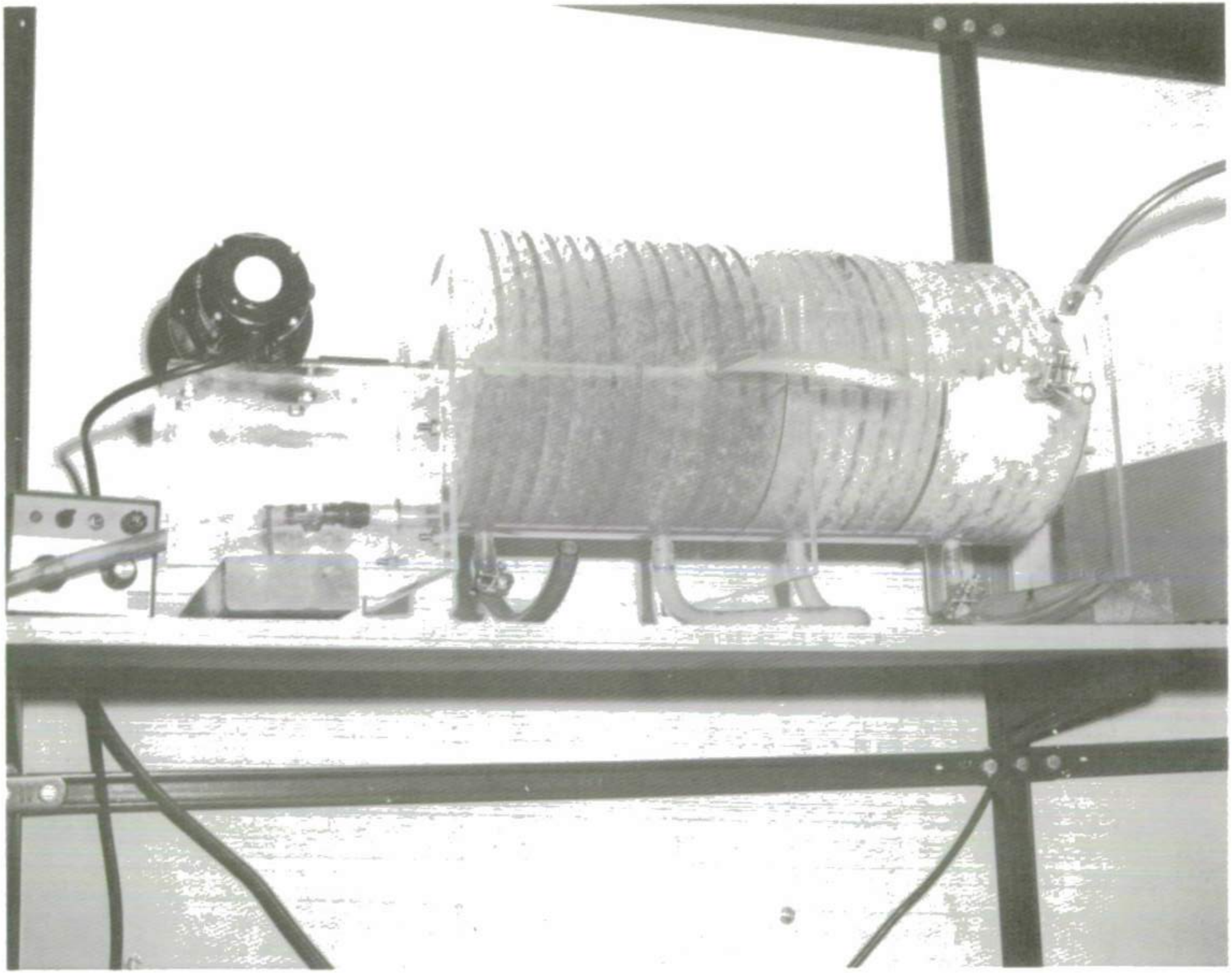

Figure 4. The aerobic biodisc unit.

The wastewater was pumped from the anaerobic unit into an aeration chamber through which air was bubbled. The clarifier followed in the flow pattern and the effluent was pumped into a sand filter column and on through a carbon column containing Filtersorb 400. The two columns were of Plexiglas construction with 0.6-cm (¼-in.) walls, inner diameter 7.3 cm (2-7/8 in.), and height 122 cm (4 ft). The effluent from the carbon column was then discharged into a sewer drain.

After one month the experimental apparatus was modified for reasons given in Section VI, DISCUSSION. The following pieces of equipment were removed: sand and carbon filter columns, anaerobic biodisc unit, 1100-litre feed tank, and clarifier.

3. **System Startup.** The bench-scale biodisc study began in early May 1979. Seeding of the biodisc units was accomplished with primary effluent from the Fort Belvoir wastewater treatment plant. When no growth appeared on the discs after 2 weeks, pH adjustments and nitrogen and phosphorus additions were found to be necessary. After roughly 1 month, during which time four 1100-litre batches of synthesized wastewater had been mixed and processed by the system, COD removal of a measurable degree began to occur and growth appeared in all four chambers of the biodisc unit. Heaviest growth appeared in chambers 1 and 2. No growth was found on the anaerobic biodisc unit, nor was any gas produced by this unit.

After A-stream and B-stream testing had been completed, some repairs were necessary, and the discs were cleaned of all growth. In restarting, inoculum was taken from the pilot plant at Atlantic Research Corporation which was testing with A-stream test water. Good growth and COD removal took place within 2 weeks.

4. **Sampling and Analysis.** Parameters which were measured and analytical methods which were used are shown in Table 3.

The influent feed tank was continuously monitored for pH and pH was tested on all samples taken for COD determination. COD tests were run on influent and effluent, roughly on a daily basis. For one period of the study, COD levels in all four chambers were determined. Five-day Biochemical Oxygen Demand and Total Organic Carbon (TOC) were determined periodically in an attempt to establish a correlation with COD values.

Analysis of the microbiological growth was done at the US Army Natick Research and Development Command, using culture techniques and visible identification.

The Ames test was run by Atlantic Research Corporation with the five tester strains of Salmonella typhimurium.

IV. RESULTS

Table 4 shows a comparison between predicted and actual A-stream characteristics.

Figure 5 shows percent COD removal and BOD_5 removal vs. days of testing on A-stream 1 June – 10 August 1979.

The following figures show percent COD removal vs. pounds of COD loading per thousand square feet of disc surface area per day:

Figure 6: A-stream test results 20 July – 10 August 1979.
Figure 7: B-stream test results 27 August – 21 September 1979.
Figure 8: A-stream test results 17 October – 28 December 1979.

Figure 9 shows percent COD removal vs. days of testing on ammonia-still-bypass water 7 January – 8 February 1980.

Toxicity and mutagenicity test results from Atlantic Research Corporation appear in Section V.

V. RESULTS OF ATLANTIC RESEARCH ANALYSIS FOR TOXICITY AND MUTAGENICITY

In order to provide a complete picture of the analysis done on the effluent from the bench-scale biodisc unit, selected information has been drawn from the final report by Atlantic Research Corporation.*

5. **Toxicity of RBC Influents and Effluents to the Bluegill Sunfish.** In toxicity studies done by Atlantic Research, the LC_{50} for 24-, 48-, and 96-hour exposure of bluegill sunfish (Lepomis macrochirus) to the RBC influent, effluent, and granulated carbon filtrate are presented in Table 5. The water parameters for the test solution are given in Table 6. The influent B-stream was found to be highly toxic to the bluegill sunfish with LC_{50} values between 1 and 1.5 percent volume/volume (% v/v), depending on the length of exposure. The toxicity of the B-stream effluent was much

* Judith F. Kitchens et al, "Pilot-Scale Evaluation of the Treatability of RDX/HMX Site 'X' Facility Wastewaters." Atlantic Research Corporation, Final Report ARCSL-CR-80028 for Contract DAE 18-69-A-0223 (Apr 80).

Table 3. Parameters Measured and Analytic Methods Used

Parameter	Method
Biochemical Oxygen Demand	*Standard Methods,** p. 555.
Chemical Oxygen Demand	*Standard Methods,** dichromate reflux method, p. 550.
Total Organic Carbon	*Standard Methods,** Dohrmann TOC Analyzer, p. 532.
pH	Beckman pH meter
Temperature	Thermometer
Nitrogen: Ammonia, Nitrate, Nitrite	Hach Chemical Company, *Water Analysis Handbook* (1977).
TNT, RDX, HMX	Waters Liquid Chromatograph, Radial Compression Separation System, using a C18 Microbonded Column, 75% Acetonitrile, 25% Water solvent.

*American Public Health Association, *Standard Methods for the Examination of Water and Wastewater, 14th edition,* APHA, Washington, D.C. (1975).

Table 4. Comparison Between Predicted and Actual A-Stream Characteristics

Characteristic	Predicted	Actual
pH	5.5-7.3	3
BOD_5 (mg/l)	198	1390
COD (mg/l)	286	1650

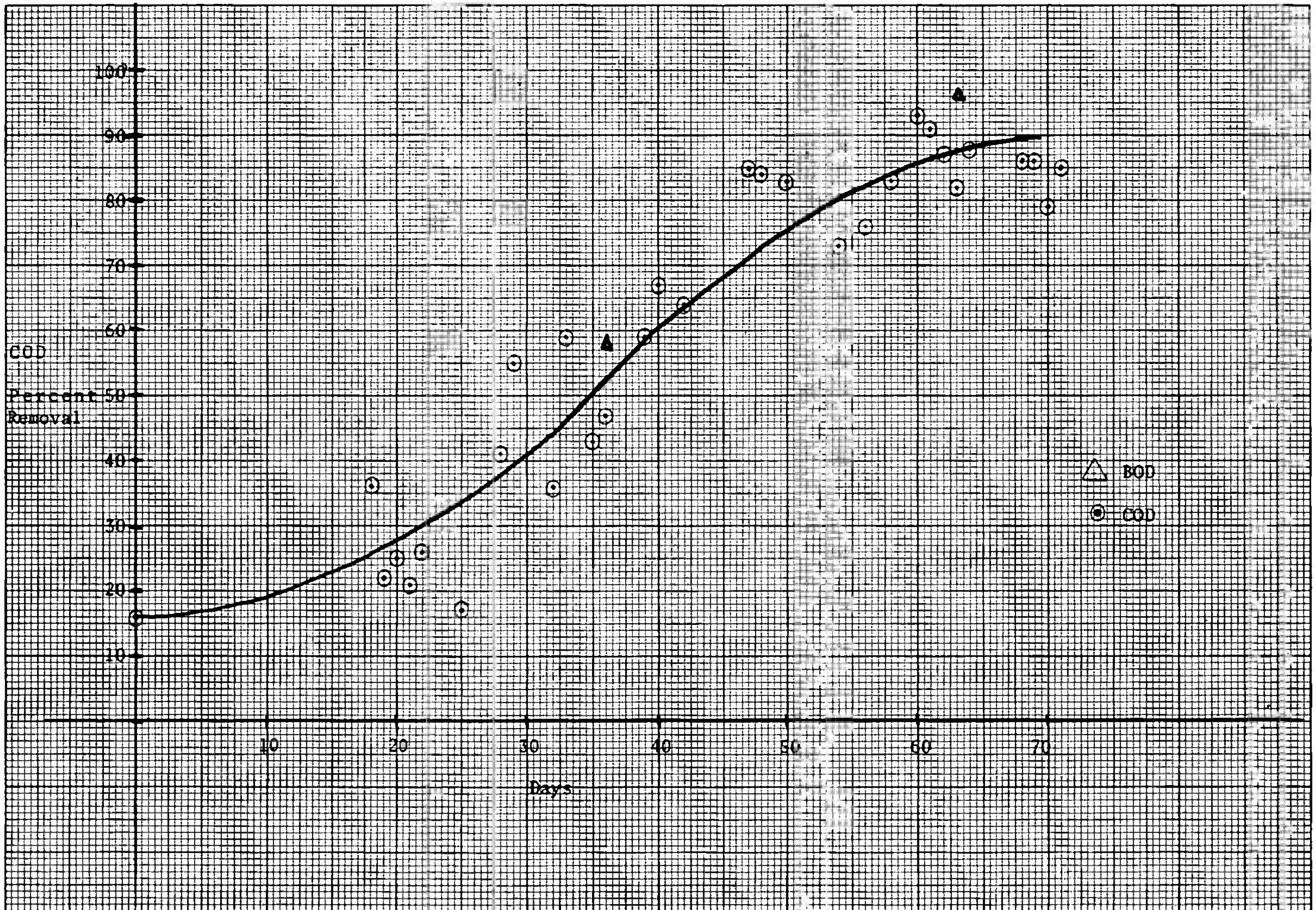

Figure 5. A-Stream test results, 1 June—10 August 1979.

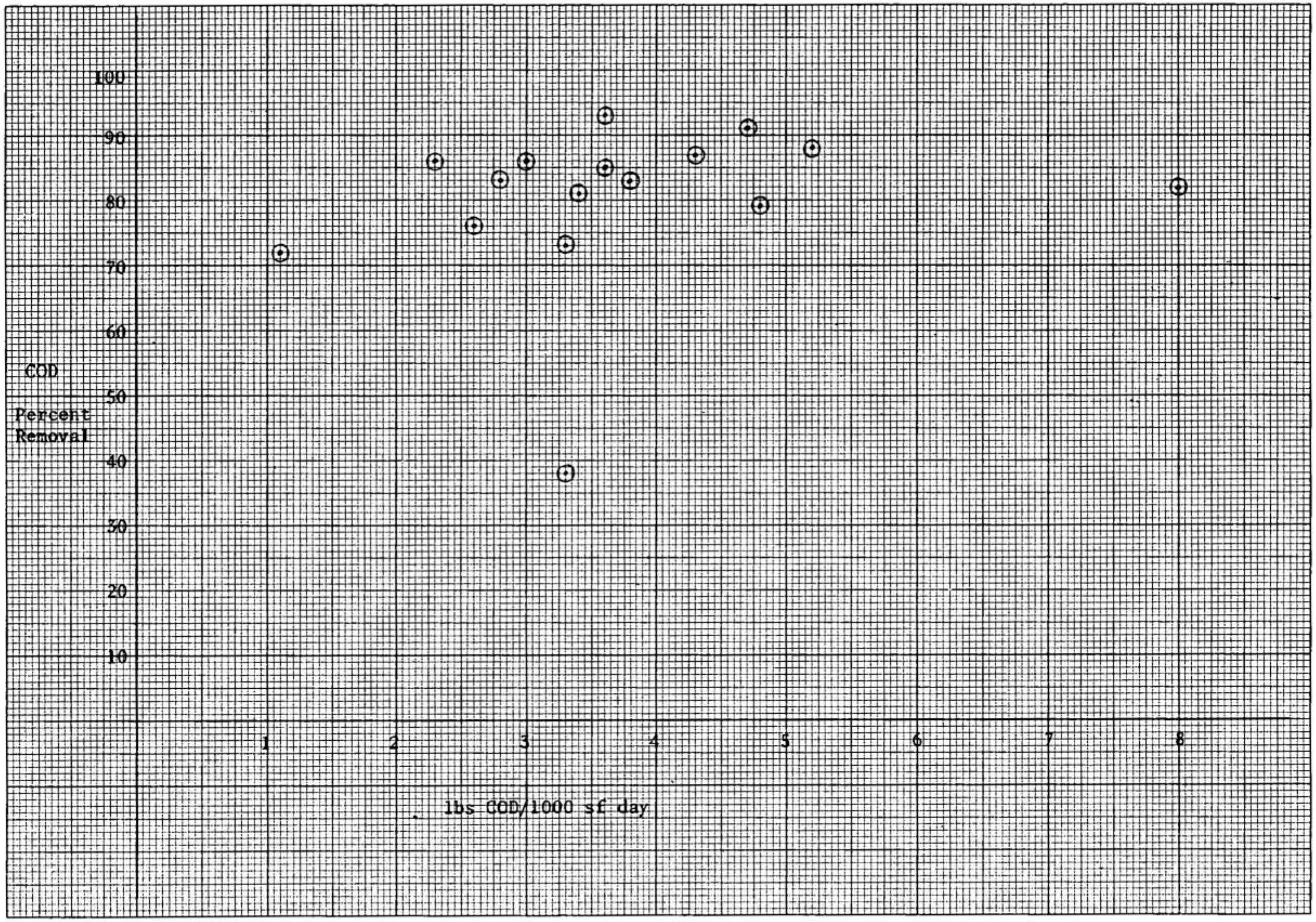

Figure 6. A-Stream test results, 20 July—10 August 1979.

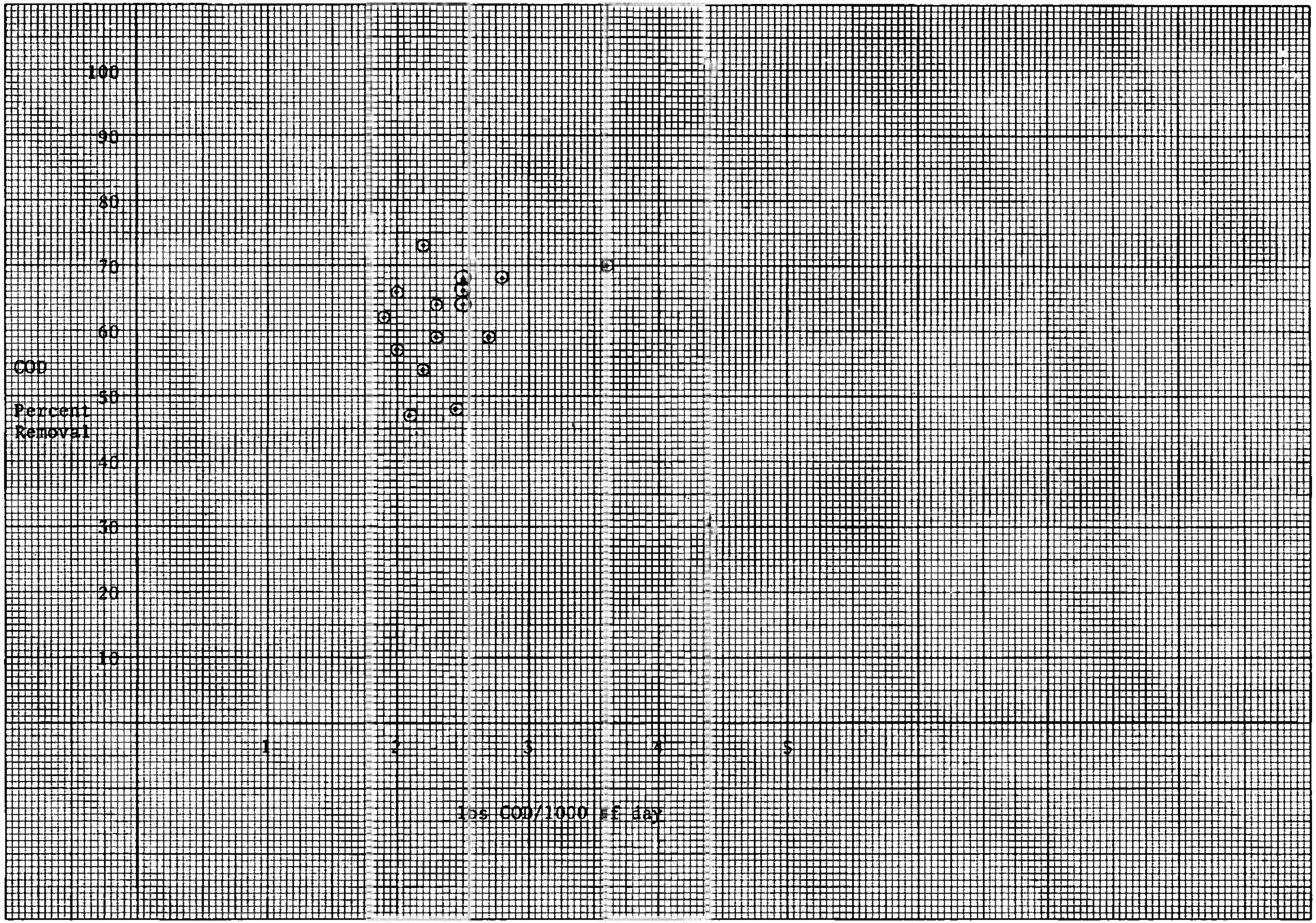

Figure 7. B-Stream test results, 27 August—21 September 1979.

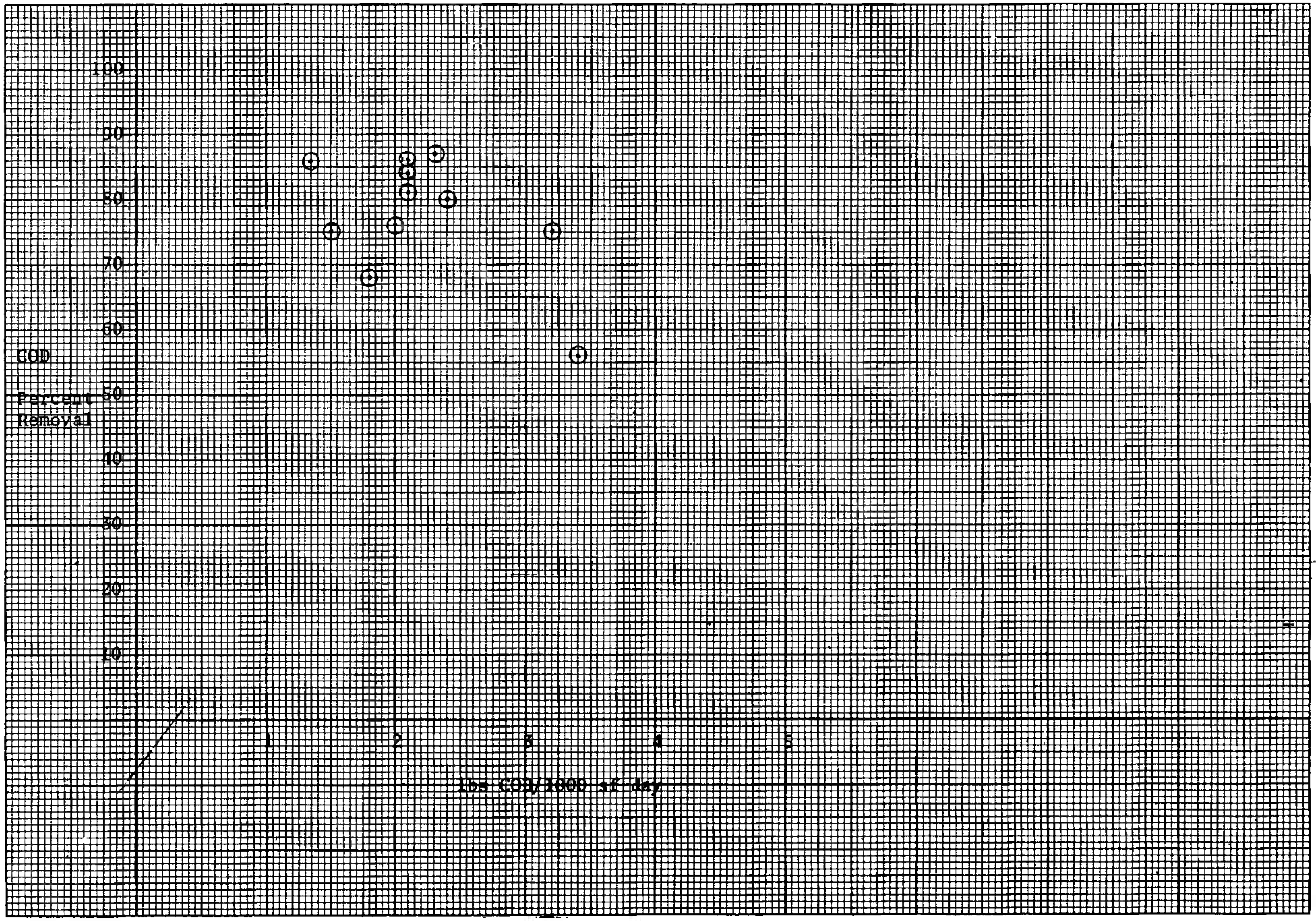

Figure 8. A-Stream test results, 17 October—28 December 1979.

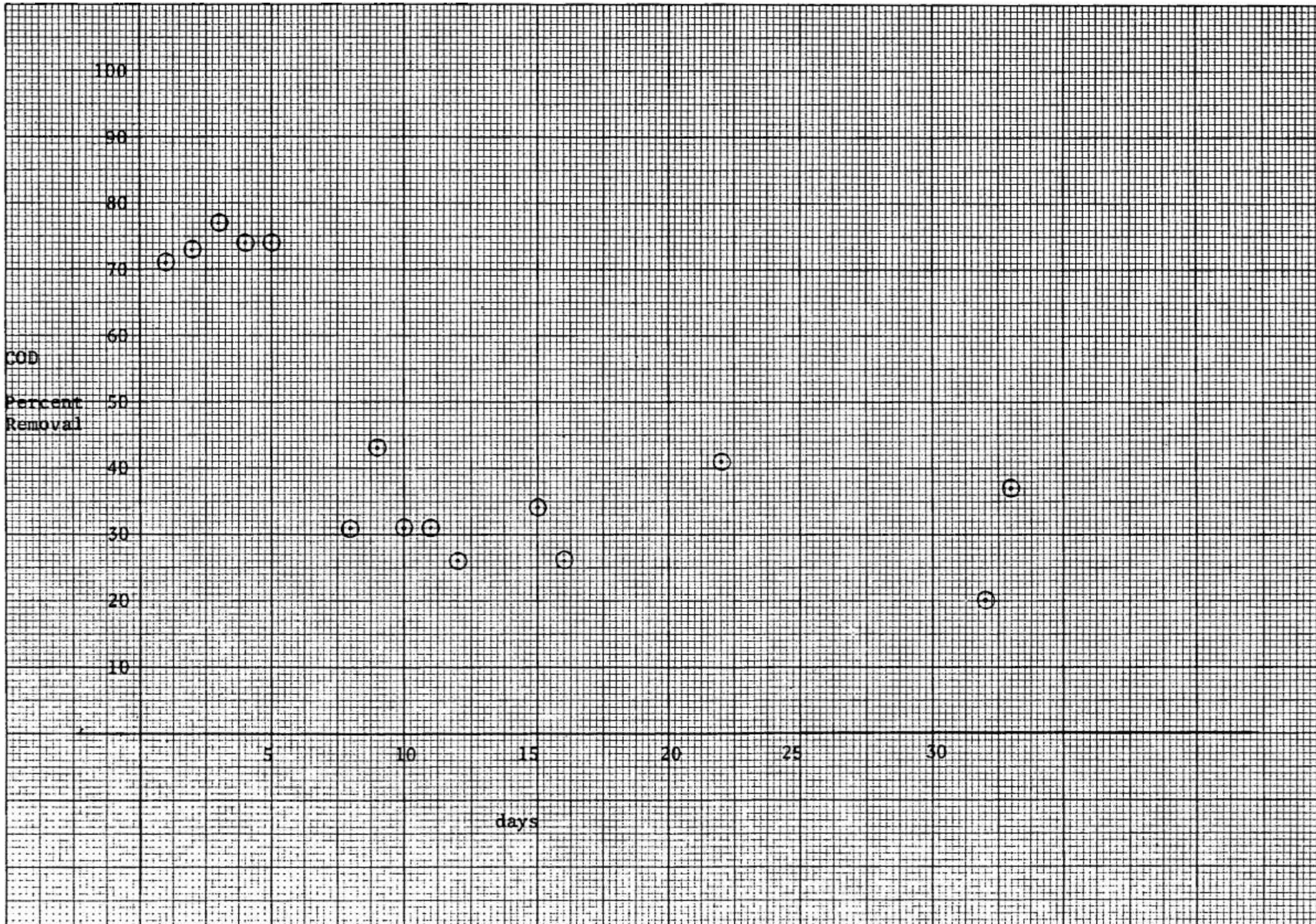

Figure 9. Ammonia-still-bypass water test results, 7 January–8 February 1980.

Table 5. Toxicity of RBC Influent and Effluents to the Bluegill Sunfish (Lepomis macrochirus)

Sample	Hours	LC_{50} Mixture in % v/v	95% Confidence Range in % v/v
Influent, B-Stream 4 Oct 79	24	1.5	1.0-2.1
	48	1.3	0.8-1.9
	96	1.0	0.6-1.8
Effluent, B-Stream 4 Oct and 12 Oct 79	24	46.5	39-56
Effluent, B-Stream (No TNT) 11 Dec 79	24	37.0	29-47
Effluent, B-Stream 14 Dec 79	24	45% death at 85%	–
	48	74.0	51-100
Carbon Filtrate, 2 ft 1 Nov 79	24	55.0	43-70
Carbon Filtrate, 6 ft	24	30% death at 60%	–
	48	30% death at 60%	–

Table 6. Stream Parameters for Aquatic Toxicity Tests

Parameter	B-Stream Influent 4 Oct 79	B-Stream Effluent 4 Oct 79	B-Stream Effluent 12 Oct 79	B-Stream Carbon Filtrate 1 Nov 79	B-Stream Effluent (No TNT) 11 Dec 79	A-Stream Effluent 14 Dec 79
pH	8.35	8.75	8.5	8.0	8.65	8.1
D.O.*	8.8 ppm	13	10.0	9.2	8.0	> 8.0 ppm
Alkalinity	108 ppm	588 ppm	422	310 ppm	1162 ppm	–
Nitrate-N	–	1 ppm	2 ppm	–	1.2 ppm	1.0 ppm
COD	1868 ppm	529 ppm	266 ppm	18 ppm	229 ppm	374 ppm
BOD	1274 ppm*	305 ppm	143 ppm	–	41 ppm	20 ppm
Formaldehyde	1340 ppm	33 ppm	40 ppm	–	33 ppm	–
RDX	> 10	> 10	6.5 ppm	–	–	–
HMX	0.6 ppm	0.6 ppm	0.3 ppm	–	–	–
TNT	1.6 ppm	BDL	0.6 ppm	–	0	–

* Values lower than actual due to insensitivity of the dissolved oxygen probe.

BDL – below detection limit of approximately 0.1 ppm

– not measured

lower than the influent, with a 24-hour LC_{50} of 46.5% v/v. The LC_{50} of the B-stream effluent was 37% v/v when no TNT was included. In Atlantic Research's opinion these tests indicate that TNT and its transformation products are not the primary cause of the acute toxicity of the wastewater to the bluegill sunfish. The toxicity of the B-stream effluent appeared to be independent of the COD reduction and could, therefore, be due to one of several factors: high salt levels, residual toxic materials not removed by the RBC microorganisms, or biotransformation of an influent constituent into a toxic material.

The toxicity of the A-stream RBC effluent was less than that observed for the B stream. The A stream had a concentration of approximately 0.65 that of the B stream in terms of organic pollutants. However, the 24-hour aquatic toxicity of the A stream was less than 0.55 times that observed with the B stream. Further research could be done into effluent components of the B stream and their identification to determine why the B stream is more toxic than would be predicted from the A-stream results.

Treatment of the munition wastewater stream by the RBC substantially reduced the toxicity of the stream. The carbon filtration of the RBC effluent also reduced this toxicity, although a large amount of activated carbon was required. The removal of TNT from the wastewater stream did not substantially change the toxicity of the effluent.

6. **Mutagenicity Testing on the RBC Effluent.** Atlantic Research Corporation ran the Ames mutagenicity test on four water samples; i.e., their B-stream effluent, their carbon column effluent, the MERADCOM A-stream effluent without explosives, and pink water from the Iowa Army Ammunition Plant.

Mutagenicity was clearly indicated for all B-stream samples on all tester strains without use of biological activation. The inference drawn here was that multiple mutagens were present and were using different mechanisms. The carbon column effluent samples were not clearly mutagenic in this test. The MERADCOM A-stream sample without explosives as well as the Iowa pink water, which contained significant amounts of TNT, were tested. No clear indication of mutagenicity was found for these samples.

Subsequent testing of the MERADCOM B-stream influent without TNT gave no clear evidence of mutagenicity.

VI. DISCUSSION

7. **Startup Problems.** After startup of the system in early May, no growth appeared on either the anaerobic or aerobic biodisc units in spite of the seeding which had taken place. It was discovered that the lack of growth was due to highly acidic pH levels of around 3 and the absence of sufficient nitrogen and phosphorus as nutrients required to support respiration of the microorganisms. Ammonium hydroxide was used daily on a batch basis to adjust the pH to a level around 7.0 for 2 weeks from 21 May through 1 June 1979. In spite of this batch leveling of pH, large drops in the pH level continued to occur each night. At the same time, biomass was beginning to grow on the discs, though frequent sloughing of this biomass took place. Adjustment of pH on an automatically monitored basis was implemented on 4 June 1979 and continued through the end of the testing. The sloughing problem abated once the pH was maintained in the neutral range.

In the parallel pilot-scale experiment being conducted at Atlantic Research Corporation, sodium hydroxide and ammonium hydroxide were used to adjust pH. Their experimental apparatus was slightly different in that they used a small tank with a pH controller between the feed tank and biodisc unit. This allowed the feed tank contents to drop to low pH levels yet assured a neutral pH in the influent to the biodisc.

The influent as described in Table 1 was deficient in nitrogen and phosphorus as noted above. Microorganisms use carbon, nitrogen, and phosphorus in an approximate molar ratio of 106 to 16 to 1. The ammonium hydroxide used to neutralize the influent provided sufficient nitrogen, but supplemental phosphorus, in the form of sodium phosphate, was required. Sixty-six mg/l of Na_2HPO_4 was added to the feed water in the A-stream testing.

Once these two nutrients were added, substantial growth appeared within a week. COD removal efficiency increased dramatically as well.

8. **Wastewater Characteristics.** Characteristics of the wastewater formulated for testing purposes as predicted by ARRADCOM were found to be markedly different from the characteristics actually determined by analysis of the A stream and B stream. Predicted pH values between 5.5 and 7.3 were found to be closer to pH 3.

Based on information from ARRADCOM, BOD_5 and COD expected values for A stream were 198 mg/l and 286 mg/l, respectively. Analysis showed these values to be 1390 mg/l and 1650 mg/l, respectively.

The microorganisms were able to deal with the heavy loadings at A stream, and BOD_5 removal rates of 95% were obtained. The problem which arises, however, is that the 5% which remains at those heavy loadings amounts to around 140 mg/l of BOD_5. It is unlikely that a NPDES permit would allow such a high value of BOD_5 in the effluent.

9. **Possible Influent Toxicity.** Without pH adjustment, the A stream adversely affected biological growth. Following pH adjustment and addition of nutrients, results indicated that the system could become acclimated to the feed stream.

By the end of the testing program, it was apparent that neither the explosives nor the high levels of formaldehyde and formic acids inhibited the biological growth to any noticeable degree.

10. **Microorganism Identification.** In the course of the investigation, it appeared that the number of different organisms was not as large as is normally found in sewage treatment plants using RBCs. Evidence was sought that the microorganism growth was not a pure culture which would be susceptible to total kill should some parameter change.

Samples were drawn from each of the four chambers of the biodisc and sent by overnight mail to the US Army Natick Research and Development Command in Natick, Massachusetts. Their test results showed that the growth was not a pure culture. In fact, it was found to consist of two strains of fungi and seven different colonial morphologies. The two fungi identified were *Fusarium* sp. and *Geotrichum* sp. Three pseudomonads were isolated; one from the pseudomonas genus and two pseudomonad organisms. Two common bacillus organisms of a ubiquitous nature rounded out the types of microbes found.

No further analysis was done to classify the organisms once it was apparent that they were typical of normal sewage system organisms. Obtaining seed material would not be difficult should a massive kill take place.

11. **System Alterations.** A number of alterations in the physical setup took place over the course of the experiment. The first was removal of the sand and carbon columns due to plugging from growth of microorganisms which appeared similar to those present on the discs. These columns are described in Section III, paragraph 2 of this report. Backwashing the columns was not effective in unplugging the columns as the microorganisms formed flake-like clumps, too heavy to remove by backwashing. Both sand and carbon provide good growth media. Plugging of these filters by biological growth would be a problem at plant level.

No growth occurred on the discs rotating in the anaerobic biodisc unit. No gas evolved from this unit either. The second alteration to the system was removal of the anaerobic unit. Possible explanations for the lack of growth include the relative sensitivity of methane formers and the wide fluctuations in pH and flow rate to which the system was subjected at startup.

The third alteration was in feed tank size. Extensive biological growth had taken place in the 1100-litre tank and reduction of COD was taking place before the influent got to the RBCs for processing. To improve the experimental design by reducing feed tank retention time, the 1100-litre tank was eliminated. Mixing was done in the 120-litre tank in the hope that this shorter retention time would prevent growth. For the major portion of testing, the system was pared down to the functioning units shown previously in Figure 4. At the end of the testing program, growth in even the smaller feed tank had become a problem, and further testing would have called for additional modification of the feed flow system.

12. **Flow Rate and Control.** Control of the flow rate of the wastestream by Masterflex pump was equivalent to control of loading of BOD per unit of disc area since there was no recycling in the system. Initial difficulty was experienced in achieving a fine level of control of this flow rate due to lack of calibration of the pump and pump head being used. In addition, as time passed the tubing changed shape and it was necessary to recheck the flow rate on a daily basis. Control of feed flow was critical, particularly in such a small system, since minor variations in millilitres of flow per minute were equivalent to major variations in BOD loading on the disc area per day.

13. **Rotation Rate.** The amount of dissolved oxygen (DO) present in the wastewater, and therefore available to the microorganisms, was controlled by the rotation rate of the discs. In order for the microorganisms to accomplish synthesis and respiration, sufficient DO must be present. Throughout the testing, disc revolutions were set a 17.5 r/min which, for this diameter disc, is equivalent to an edge velocity of 0.24 m/s (0.78 ft/s).

Direct measurement of the DO levels in the disc chambers was not possible for this test program because available DO probes would not fit into the necessarily small clearance between discs and chamber walls. The Winkler method was not used because it was not possible to withdraw a sample of sufficient volume without upsetting the system.

In addition to providing for dissolved oxygen to the biomass, a second function of disc revolution was the shearing force exerted on the biomass attached to the discs. When the discs rotated with sufficient velocity, the biomass layer remained thin. This allowed DO transfer through the layer and avoided the formation of an anaerobic layer adjacent to the disc.

The fact that high levels of COD reduction were attained and growth appeared on discs of all four chambers was taken as an indication that sufficient dissolved oxygen was present.

14. Biomass Solids. During startup, sloughed biomass often plugged the normal flow pathway overnight. This caused overflow of chambers 1 and 2 (Figure 4) and radically changed retention times. Minor plumbing alterations alleviated this situation. However, the biomass which grew in the RBC chambers caused other problems.

Because the sloughed biomass was occasionally removed manually, it did not accumulate to the point where the flow was stopped. If allowed to accumulate, the bulk of it would have scraped the discs clean of growth and eventually the biomass would have become septic.

The effluent solids did not settle well. This tendency not to settle could cause difficulty in a full-scale plant. Due to total suspended solids limitations which will be contained in the NPDES permit, clarification of the biodisc effluent will be necessary. In addition, the tendency of this biomass to cause plugging of filters and flow lines will require special removal techniques.

15. Seed. As mentioned earlier, initial seed consisted of effluent taken from a local sewage treatment plant. Inoculum from the Atlantic Research Corporation's pilot plant was used twice in reseeding. It is noteworthy, however, that total kill did not take place even under very adverse conditions. It was visually apparent that some microorganisms always remained. The microbial growth reestablished itself quickly each time and was virtually self-seeding.

It would be necessary, of course, to seed at initial startup and at any time the discs were completely free of growth.

16. Scale-up. There was a question at the beginning of this study as to whether the results of bench-scale testing could be scaled up to give pilot level parameters.

From the data obtained, it can be concluded that scale-up is possible. This conclusion is fortified by the fact that similar removal efficiencies were attained with both bench- (MERADCOM) and pilot-scale (ARC) systems when comparisons were made using loading rates per unit of disc surface area with A-stream testing.

17. **Startup Time Requirements.** Figure 5 shows COD and BOD_5 removal efficiencies from startup through attainment of optimum BOD_5 removal (97%) during initial startup. Ten weeks passed before this optimum level of removal was attained. In the course of those 10 weeks, numerous mechanical and chemical feed problems were encountered. Several of these problems have been mentioned, including biomass sloughing, pH adjustment, and flow regulation. In contrast, once those problems had been dealt with, a later clean disc startup took only 2 weeks to achieve the same removal level.

A clean disc startup requirement is not a likely occurrence because of the hardiness of the microbial population in the face of adversity. An exception would be initial startup.

18. **TNT/RDX/HMX Removal.** From analyses conducted on the liquid chromatograph at MERADCOM, it was apparent that TNT, RDX, and HMX were not being removed by the system. RDX and HMX concentrations were unchanged from influent to effluent. The TNT, while in the feed tank, underwent some structural changes. The products were not characterized because of time limitations, but it should be noted that although the TNT was transformed, it is not reasonable to conclude that the contamination problem has been dealt with. It is known that TNT is readily transformed into toxic compounds, such as dinitrotoluene.

Because of the inability of RBCs to remove the explosives, these contaminants will have to be removed before the process stream is fed to the biodisc unit. For this reason, experiments following the initial tests were done with a feed water synthesized without explosive contaminants.

19. **Operation on B-stream Wastewater.** Changeover to B-stream was followed by a sizeable drop in COD removal efficiencies. The ratio of carbon contained in the B-stream formula to carbon contained in the A-stream formula is approximately 1.6 to 1. The initial B stream fed to the biodisc contained 70% of the concentration of constituents indicated in Table 2. Therefore, the composition of this initial B-stream flow was only slightly more concentrated than the A-stream flow, although the contaminants in each stream were the same and differed only in concentrations. As indicated in Figure 7, erratic results were obtained at 70% B stream. In further tests with 100% B stream, removals varied from 73% down to 17% for undetermined reasons.

In contrast to this performance, the pilot plant at Atlantic Research switched to 100% B stream and achieved 90% removal within the first week after the changeover.

20. Operation on Ammonia-Still-Bypass Wastewater. The microorganisms had a great deal of trouble responding to the shock of the ammonia-still-bypass wastewater loading. Although raw data in Appendix C show a few days of removal rates in the 70 percent range, no consistency was achieved during the month of testing on this stream as indicated in Figure 9.

At this point in the testing, close supervision of the unit was not possible because of personnel limitations. For this reason, some doubt exists as to whether the poor level of COD reduction was due to operation or to constituents in the new formula. Further investigation would be required to determine if it would be feasible to treat the ammonia-still-bypass wastewater with a biodisc system.

21. Data Interpretation. In Figures 6 through 9, single data points are shown with no connecting curve. No curves were drawn because of the variability in data points. The authors' intent is to avoid leading the reader to erroneous conclusions as to the stability of the removal rate.

VII. CONCLUSIONS

22. Conclusions. Based on the data obtained in this study, the following conclusions are drawn:

a. At an average loading of 2.3 lb COD/1000 ft^2 day, removal of 82% of COD was attained in treatment of the more dilute wastestream in the testing performed in October through December.

b. In the testing which was performed in June through August, a higher loading of 3.6 lb COD/1000 ft^2 day gave the same COD removal.

c. In the treatment of the more concentrated wastestream, removals of 62% of COD were attained at a loading of 2.3 lb COD/1000 ft^2 day.

d. pH values near 3 of the influent hinder biological treatment. The influent must be neutralized prior to treatment.

e. Phosphorus and nitrogen supplements were necessary to allow growth of microorganisms. Calculations indicate that requirements for nitrogen and phosphorus at the plant level would be quite high.

f. Formaldehyde and formic acid in the high concentrations used were not toxic to the microorganisms.

g. Several different microorganisms populated the aerobic biodisc unit. Many were typical of sewage treatment plant microorganisms.

h. The microorganisms which populated the system were extremely hardy, indicating that the possibility of a total kill-off was remote.

i. Filtering was a problem with this culture on both sand and carbon filter columns due to the spore-forming nature of the microorganisms.

j. High levels of COD reduction will occur in the equalization pond used in the proposed X-Facility treatment system if pH neutralization is provided.

APPENDIX A

A-STREAM OPERATION DATA

Date	1 June	18 June	19 June	20 June	21 June	22 June	25 June	28 June	29 June	2 July	3 July	6 July	6 July	9 July
Infl	1480	1481	1488	1606	1464	1630	1574	1500	1423	1246	1290	1589	1547	735
I														
II														
III														
IV														
Effl	1240	955	1169	1204	1162	1200	1300	890	640	792	525	979	820	300
Removal (%)	18	36	22	25	21	26	17	41	55	36	69	43	47	69
Flow Rate														
(ml/min)		135	13565	65	66	65	65	65	65	80	60	65	65	60
							phosphate				sloughing			
							nutrient				scrubbed			
BOD							added		pH=3		discs			
Infl													1100	
Effl													465	
Removal (%)													58	

APPENDIX A (CONT'D)

Date	10 July	11 July	12 July	17 July	18 July	20 July	23 July	24 July	25 July	28 July	27 July	30 July	31 July	1 Aug
Infl	508	1280	1208	910	755	1820	1584	1731	1779	1547	1369	1384	1666	1646
I										827	469	593	717	732
II						731	1018	422	352	408	433	335	528	533
III						55	1010		354	345	395	220	238	270
IV								343		455	236	177	166	268
Effl	203	486	435	135	118	311	979	462	338	392	343	101	143	215
Removal (%)	57	52	64	85	84	83	38	73	81	78	83	93	91	87
Flow Rate (ml/min)	60	60	60	40	40 switch from 300-gal to 120-l feed tank	20	20	18	18	15	19	25	27	26

Date	3 Aug	7 Aug	8 Aug	9 Aug	10 Aug	17 Oct	19 Oct	24 Oct	2 Nov	6 Nov	13 Nov	14 Nov	20 Nov	23 Nov
	new feed													
Infl	2159	2015	1420	1834	1810	2192	2718	1740	1736	1837	1571	1203	1729	1086
I	324	333	516	750	686									
II	801	390	312	662	413									
III	1212	358	214	455	278									
IV	407	325	241	418	255									
Effl	264	284	199	383	263	969	1756	1249	277	224	401	411	1264	386
Removal (%)	88	86	86	79	86	56	35	28	84	86	75	66	27	65
Flow Rate (ml/min)	23	11	20	25	19	13	9		10	7	8			
BOD_5														
Infl	1600													
Effl	70													
Removal (%)	96													

Date	28 Nov	29 Nov	30 Nov	3 Dec	5 Dec	13 Dec	17 Dec	20 Dec	27 Dec	28 Dec
Infl	1120	1496	1584	1029	1701	1460	1569	1230	1892	1541
Effl	271	205	329	327	327	601	477	155	478	202
Removal (%)	78	86	80	68	81	59	70	87	75	87
Flow Rate (ml/min)	15	12	13	15	11				14	13

APPENDIX B

B-STREAM OPERATION DATA

Date	13 Aug	14 Aug	15 Aug	16 Aug	17 Aug	20 Aug	21 Aug	22 Aug	23 Aug	24 Aug	27 Aug	28 Aug	29 Aug	30 Aug
Infl	2216	2218	2034	2192	2709		2218	2224	2112	1842	2520	2013	2123	1991
I	648	723	569	832	1106	1217	1128	1239	1106	1217	1368	1059	743	928
II	670	653	586	832	1043	941	1116	866	891	764	1019	959	899	909
III	534	457	407	704	1007	751	797	788	792	777	984	1037	836	944
IV	459	430	400	632	826	936	685	798	760	737	1056	731	922	941
Effl	496	438	428	653	930	972	717	740	771	769	1024	1070	977	1043
Removal (%)	78	80	79	70	66		68	67	63	58	59	47	54	48
Strength (%)	70	70	70	70	75	75	80	80	80	100	100	100	100	100
Flow Rate (ml/min)	19	15	16	10	18	18	18	15	18	15	10	10	10	10
BOD_5														
Infl	1655													
Effl	100													
Removal (%)	94													

Date	31 Aug	4 Sept	5 Sept	6 Sept	10 Sept	11 Sept	12 Sept	13 Sept	17 Sept	20 Sept	21 Sept	24 Sept	25 Feb	5 Mar
Infl	2685	2105	1891	1786	2595	2405	2222	2130	2210	2346	2651	2310	2075	789
I	1033	644	683	710	1065	1010	1000	999			1023	1504		
II	641	605	641	675	911	929	936	930			915			
III	821	617	602	663	880	881	931	949			791			
IV	776	621	614	675	849	854	905	942			775			
Effl	866	578	641	671	880	877	913	919	803	761	786	1480	300	656
Removal (%)	68	73	66	62	66	64	59	57	64	68	70	36	86	17
Strenght (%)	100	100	100	100	100	100	100	100	100	100	100	100		
Flow Rate (ml/min)	10	10	10	10	9	10	10	9	10	10	13 mechanical failure	12	12	0
Infl BOD_5	1955									1380				
Effl	97									210				
Removal (%)	95									85				

Date	7 Mar	10 Mar	11 Mar	14 Mar	18 Mar	25 Mar	31 Mar	2 Apr	4 Apr	11 Apr
Infl	2031	1440	1051	2484	2286	2290	1594	604	2805	2868
Effl	625	772	627	727	448	502	375	415	2130	815
Removal (%)	69	46	40	71	80	78	76	31	24	71
Flow Rate (ml/min)	10	11	10			12	8	15		14

APPENDIX C

AMMONIA-STILL-BYPASS WATER DATA

Date	7 Jan	8 Jan	9 Jan	10 Jan	11 Jan	14 Jan	15 Jan	16 Jan	17 Jan	18 Jan	21 Jan	22 Jan	28 Jan	7 Feb	8 Feb
Infl	1117	2740	2660	2150	1929	2352	3020	3873	2872	2617	2662	2449	2228	2380	2820
Effl	321	740	600	567	506	1623	1710	1961	1977	1929	1769	1819	1305	1910	1780
Removal (%)	71	73	77	74	74	31	43	31	31	26	34	26	41	20	37
Flow Rate (ml/min)	13.5				12	11	13	11	15						

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